Social Cues Support Learning about Objects from Statistics in Infancy

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Abstract

In laboratory experiments, infants can learn patterns of features that co-occur (e.g., Fiser & Aslin, 2002). This finding leaves two questions unanswered: What do infants do with the knowledge acquired from such statistical learning, and which patterns do infants attend to in the noisy and cluttered world outside of the laboratory? Here, we show that 9-month-old infants form expectations about co-occurring features remaining fused, an essential skill for object individuation and recognition (e.g., Goldstone, 2000; Schyns & Rodet, 1997). We also show that though social cues may temporarily detract attention away from learning events, they appear to stimulate infants to display learning better in complex situations than when infants learn on their own without attention cues. These findings suggest that infants can use feature co-occurrence to learn about objects and that social cues shape such foundational learning in a noisy environment during infancy.

Keywords: visual statistical learning; eye-tracking; cognitive development; social cues; eye gaze.

Introduction

Knowing *what* to learn is fundamental to all aspects of development. In particular, recognizing important features in a display and the relationships between them supports essential skills such as object recognition (Biederman, 1987), categorization (Mareschal, Quinn, & French, 2002; Rakison & Butterworth, 1998; Schyns & Rodet, 1997; Younger & Cohen, 1986), and word learning (Smith & Yu, 2008). Fiser and Aslin (2002) showed that 9-month-olds prefer to look at shapes that have co-occurred previously, rather than at shapes that did not co-occur. These findings suggest that infants are sensitive to statistical information about features in their visual environment, and support a growing literature showing that infants recognize such co-occurrence information within auditory and visual modalities (Kirkham, Slemmer, & Johnson, 2002; Kirkham, Slemmer, Richardson, & Johnson, 2007; Saffran, Aslin, & Newport, 1996). These findings raise two important questions. Do infants simply register these statistical patterns, or do they actually use them in order to make further predictions and inferences? In the literature on causal inference (e.g., Gopnik et al., 2004; Sobel & Kirkham, 2006), there is clear evidence that toddlers, and even infants, will go beyond the simple detection of statistical regularities among events and will use that information to make new predictions about what an object will do. Will infants similarly use the co-occurrence of features within an object to make new predictions about how that object will behave?

Moreover, in noisy natural environments infants are often presented with multiple co-occurrences. How do infants know which co-occurrences to attend to and learn from? Social cues may help infants select appropriate information. By the first few months of life, infants engage in joint attention (Butterworth, 2004), elicited by eye gaze, infant-directed speech, initial eye contact, head turn, and gestures (Carpenter, Nagell, & Tomasello, 1998; Senju & Csibra, 2008). Many investigators suggest that this attentional bias helps infants develop their social cognition and competence (e.g., understanding beliefs, desires, goals, and communicative intent, see Carpenter et al., 1998; Csibra & Gergely, 2006; Repacholi & Gopnik, 1997). However, these cues also can help shape basic cognitive development by helping infants *learn what to learn* in a noisy and exciting environment. While the impact of engaging in joint attention on social competence has been studied extensively (for review, see Carpenter et al., 1998), fewer studies investigate how following social cues can shape basic learning. Some studies have focused on word mapping (e.g., Gliga & Csibra, 2009; Houston-Price, Plunkett, & Duffy, 2006; Pruden, Hirsh-Pasek, Golinkoff, & Hennon, 2006) and learning linguistic structures (Goldstein & Schwade, 2008). Others have shown that such cues can lead to better recognition of an attended object (e.g., Striano, Chen, Cleveland, & Bradshaw, 2006) as well as to encoding an object's featural or spatial information (Yoon, Johnson, &

Csibra, 2008). Recently, Wu and Kirkham (in press) showed that social cues produce better association of audio-visual events than non-social cues (i.e., flashing squares). These findings suggest that following social cues could shape early basic learning. These conclusions, however, require stronger measures of learning than recognition of cued objects or simple matching of audio-visual events.

The present study tests whether infants develop expectations about object integrity based on the co occurrences of features with and without social attention-directing cues. This measure tests whether infants develop expectations about object integrity based on feature co-occurrence information. Earlier research shows that adults "chunk" co-occurring features into larger perceptual units (e.g., Fiser & Aslin, 2005; Goldstone, 2000). These larger units help to identify discrete objects (Baker, Olson, & Behrmann, 2004; Turk-Browne, Isola, Scholl, & Treat, 2008; for review, see Scholl, 2001). Co-occurrences can highlight the integral features of an object, the basis of visual categorization (Palmeri & Gauthier, 2004). Therefore, binding co-occurring features is an essential skill for developing veridical representations of the visual world.

Methods

Experiment 1

We investigated infants' learning of shape feature co-occurrences and whether those co-occurrences shaped their expectations about the behavior of objects (No Cue condition). Events were presented in a simple spatial layout (Figure 2, top panel), maintaining the same spatial layout between familiarization and test trials.

Participants Eighteen 9-month-old infants (9 females, *M* = 9 months, 1 day, range: 8;14-9;23) participated in this experiment. Three infants were excluded from final analyses due to fussiness (i.e., completing only two out of four blocks). Thirteen infants completed all four blocks; the remaining 5 infants completed 3 blocks. All infants were of white middle-class socioeconomic status. Infants were recruited via local-area advertisements and given t-shirts or bibs to thank them for their participation.

Apparatus Infants' looks were monitored using a Tobii 1750 eye-tracker (www.tobii.com), and events were presented on a 17" monitor attached to the eye-tracking unit. Stimuli were displayed using Tobii's ClearView AVI presentation software, and sounds were played through stereo external speakers. An external video camera on top of the screen allowed the experimenter to determine whether the infant was looking at the display. The shape events were created using Macromedia Director MX 2004, and the movie clips were assembled using Final Cut Express HD 3 (Apple Inc, CA).

Stimuli During the familiarization trials, infants watched sequences of looming shapes. Each sequence contained three patterns (Patterns A, B, and C), and each pattern was composed of 3 differently colored component shapes (see Figure 1). Each infant saw one sequence (repeatedly) during familiarization with a total of 9 shape clusters in each sequence (3 clusters per pattern, 3 patterns per sequence). For each pattern, there was a pair of shapes that were always together and a third shape that varied for each cluster. Each cluster loomed from a minimum of 4.87° to a maximum of 9.72° for 2 seconds. When a cluster grew to its maximum size, it disappeared from the screen, and another cluster appeared. A single sequence appeared in one of two white frames arranged left and right in the lower half of a black screen. Infants viewed the looming pattern while the other frame remained empty.

During the test trials, infants were shown consistent and inconsistent splitting events. Consistent events showed an animation of a cluster breaking into two, with the variable shape moving apart from the other paired shapes. Inconsistent events showed shapes that had been paired together splitting up, where one stayed with the variable shape, and the other moved apart by itself. The same test events were seen by all infants. The events were labeled as consistent or inconsistent according to the pattern that each infant saw during familiarization (i.e., a test event that was a consistent split for Sequence A was inconsistent for Sequence B, and vice versa). Thus, differences in looking time to test events were due to the exposure during familiarization rather than basic perceptual preferences. Each splitting event loomed from a minimum of 4.87° to a maximum of 8.51° for 2 seconds. Then, either a variable or constant shape split off at either a 45°, 180°, or 270° angle (relative to the vertical depending on its position in the cluster) for another 2 seconds until it reached 9.72°. These test events appeared in the same frame as the familiarization events in the lower left or right frame. Consistent and inconsistent test events were shown sequentially in the frame.

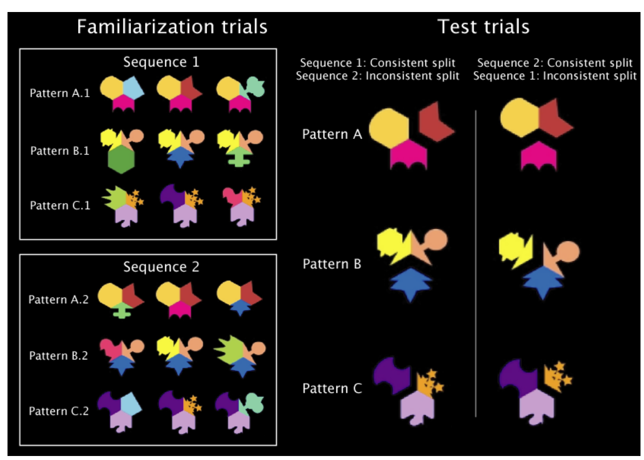

Figure 1: Shape cluster stimuli and patterns during familiarization and test trials.

Design and Procedure Infants sat in a car seat 50 cm from the eye-tracker monitor in a small, quiet room, while their caregivers sat out of their view. The caregivers were instructed to refrain from commenting on the movies or interacting with their infant. The experimenter used a 5-point calibration with a Sesame Street clip on the infants' looks. For the experiment, infants were shown four blocks of trials. Each block consisted of 6 familiarization trials (i.e., two per pattern) that lasted 6 seconds per trial, and two test trials (consistent or inconsistent) that lasted 12 seconds per trial (3 splitting events per trial, one event per pattern). During each familiarization trial, the three shape clusters in a given pattern were presented sequentially. The training sequence (Sequence 1 or 2) and presentation side were counterbalanced across infants. For each infant, the clusters in the test trials were presented in four orders, which were counterbalanced with a Latin Square across all infants. Whether the first test trial displayed an inconsistent or consistent pattern also was counterbalanced across infants. Blocks 3 and 4 repeated all familiarization and test trials from Blocks 1 and 2. Attention getters (still kaleidoscopic circles or squares with either a "bling" or "boing" sound) spliced the familiarization and test trials. The 1-second clip looped until the infants returned their gaze to the screen for approximately 1500 ms.

Coding The Areas of Interest (AOIs) encompassed slightly larger areas than those of the frames to account for noisy infant saccades. For the familiarization trials, total looking time to the AOI containing the target event was calculated with Tobii's ClearView analysis software. For the test trials, a proportional looking time difference score was calculated by subtracting the percentage of looking to the inconsistent events (total looking time to the inconsistent divided by the total looking time to both test stimuli) from that of the consistent. A negative score reflected a preference for the inconsistent splits, and a positive for the consistent.

Results Infants looked at the familiarization sequence an average of 67.15 seconds, (SE = 4.28), 46.63% of the entire presentation time. For the test trials, a one-sample t-test revealed that there was a mean preference for the inconsistent splits overall, and that this preference was significantly higher than chance, $t(17) = -2.33$, $p = .03$, two-tailed, Cohen's $d = -1.13$, $M = -.11$, $SE = .05$.

Discussion Infants displayed an overall preference for the inconsistent split. They were sensitive to the internal statistics of the shapes within each cluster, and when the two co-occurring shapes separated, this attracted their attention. One interpretation is that the infants had represented the co-occurring pair of shapes as a single object, and noticed that object breaking apart. This preference gave us a baseline of learning that allowed us to investigate how learning under more difficult conditions can be influenced by social cues.

Experiment 2

Experiment 2 increased the difficulty of the test events and examined the effect of introducing a social cue during familiarization. At test, splitting events were presented simultaneously (rather than sequentially) in the lower left and right frames. In order to explore how a social cue might influence infants' learning of the sequences (Figure 2, middle panel), infants were either shown the familiarization sequence by itself (No Cue II condition) or with a face cue that turned down to the patterns (Social Cue condition).

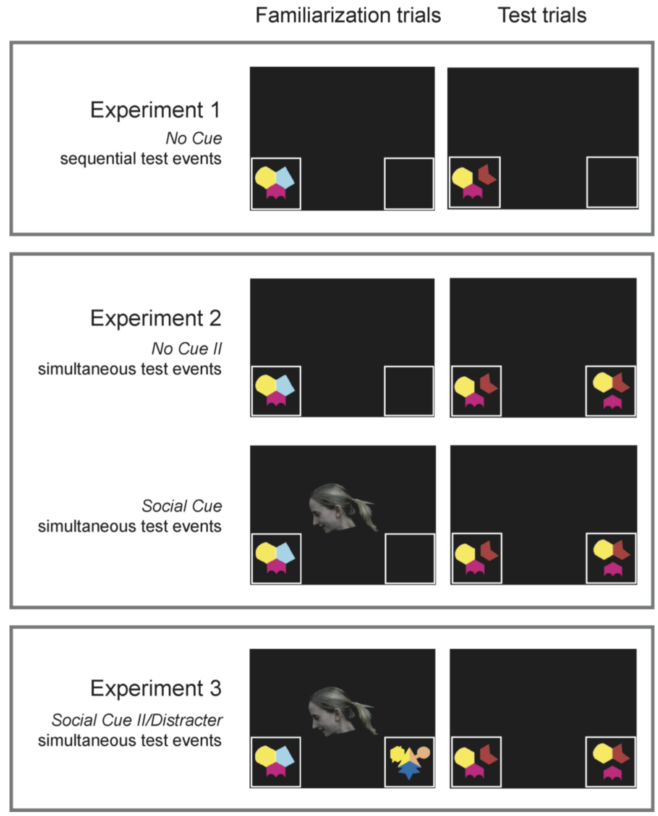

Figure 2. Familiarization and test trials for the four conditions in Experiments 1 to 3.

Stimuli Experiment 2 used the shape stimuli from Experiment 1. The familiarization trials in the No Cue II condition were identical to those from Experiment 1. For the Social Cue condition, before the onset of the shape pattern, a female face appeared in the center of the screen, looked forward, smiled, said "Hi baby, look at this!", and turned to look down at a frame. The pattern then appeared in that frame. The face stayed turned and smiling until the pattern finished (after displaying three clusters sequentially). The pattern disappeared, and the face turned back to the center and changed to a neutral expression as the trial ended. At the beginning of each familiarization trial, the face clip lasted for 5 seconds before the onset of the pattern. The face clip was filmed using Macintosh iMovie v. 4.0.1.

In this experiment, we implemented a preferential looking paradigm by presenting the consistent and inconsistent splits simultaneously in both the right and left locations to increase the complexity of the display. Locations of the splitting events were counterbalanced across infants. To maintain consistency for presentation time and trial numbers, there were two test trials per block that showed the inconsistent and consistent splits simultaneously.

Coding A central AOI was added to the familiarization trials because of the addition of the central face cue. Since the test trials now included simultaneous consistent and inconsistent splits, the difference score was calculated by subtracting the inconsistent proportional looking time from the consistent for each trial.

Results In addition to the analyses carried out in the previous experiment, we also ran a one-way ANOVA to investigate differences in total looking time during the familiarization trials between the two conditions. For the test trials, we ran a one-way ANOVA (in addition to analyses from Experiment 1) to investigate whether congruency between familiarization and test presentation side (whether infants had to switch sides to look at the inconsistent pattern) affected their preference for the inconsistent event. Infants in the No Cue II condition looked at the familiarization sequence an average of 68.39 seconds (*SE* = 5.30), 47.49% of the entire presentation time, similar to infants in Experiment 1. Infants in the Social Cue condition looked at the pattern for an average of 43.84 seconds, (*SE* = 5.53), 30.44% of the entire presentation time, because these infants split their attention between the face and target shapes. A one-way ANOVA revealed a significant effect of condition on total looking time to the target pattern during familiarization, $F(1, 32) = 10.25$, $p = .003$: Infants looked longer to the shapes in the No Cue II condition than in the Social Cue condition. For the test trials, a one-way ANOVA revealed an effect of condition (Social Cue or No Cue II) on the average difference scores, $F(1, 32) = 4.40$, $p = .04$. Thus, we divided the data set by condition to compare each set of average difference scores to chance: Infants in the Social Cue condition displayed a preference for the inconsistent split, $t(16) = -2.12$, $p = .05$, two-tailed, Cohen's $d = -1.06$, $M = -.11$, $SE = .05$, while infants in the No Cue II condition did not display a significant preference overall, $t(17) = 1.53$, $p = .15$, two-tailed, Cohen's $d = .74$, $M = .12$, $SE = .09$ (Figure 3).

A one-way ANOVA on switching sides revealed no significant effects of switching on the average difference score for both the No Cue condition, $F(1, 16) = .78$, $p = .39$, and the Social Cue condition, $F(1, 15) < .01$, $p > .90$.

Discussion With a noisier test layout, but without a social cue during familiarization, infants showed no significant preference for either the consistent or inconsistent splitting event. Infants who saw social cues during familiarization, however, exhibited a preference for the inconsistent split, similar to infants in Experiment 1. This preference discrepancy between the two conditions was not due to gross inattention to the target event. Infants in the No Cue II condition looked *longer* to the patterns during familiarization than infants in the Social Cue condition. Surprisingly, the lesser amount of attention that infants paid to the sequence in the Social Cue condition resulted in clear expectations about the objects.

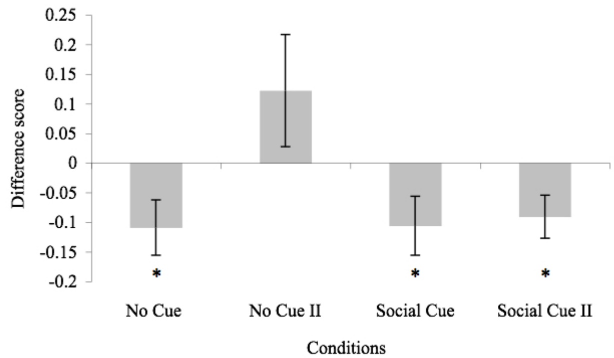

Figure 3. Difference scores across conditions (mean difference between proportional looking times for consistent minus inconsistent events during test). A negative value reflects a preference for the inconsistent splits. *p≤.05

Experiment 3

To further investigate the usefulness of social cues by increasing the noise during familiarization, we presented infants with a face turning to the target pattern while a distracter pattern played in the other frame (Social Cue II/Distracter condition, Figure 2, bottom panel).

Participants Eighteen 9-month-old infants (10 females, *M* = 9 months, 3 day, range: 8;24-9;22) participated in this experiment. Five infants completed 3 blocks, and 13 infants completed all four blocks. All infants were of white middle socioeconomic status.

Stimuli The stimuli, design, and procedure in this experiment were the same as those from the Social Cue condition in Experiment 2 except for the addition of a distracter sequence in the frame that was previously empty in Experiment 2. Infants who were directed to look at Sequence 1 had Sequence 2 as the distracter event, and vice versa. Therefore, the sequence that was the target for one infant was the distracter for another. The target and distracter patterns were displayed simultaneously during familiarization.

Coding With the introduction of a distracter during familiarization, we now measured the efficacy of social cues in directing the infants' attention to the target shape. A difference score for the familiarization trials was calculated in the same manner as for the test trials, except for the inclusion of the central AOI (face). During the test trials, the central AOI was disregarded while calculating the difference score, since there was no visual stimulus in the center during test.

Results The difference score during familiarization trials was essentially a measure of joint attention (i.e., measuring looking time to the cued rather than non-cued distracter pattern). Infants looked at the cued familiarization pattern an average of 39.14 seconds, (SE = 4.49), 27.18% of the entire presentation time. Difference scores during familiarization indicated that 17 infants (94.44%) engaged in joint attention, $t(17) = 7.67$, $p < .01$, $M = .42$, $SE = .05$. For the test trials, a t-test on the difference score revealed a preference for the inconsistent splitting events compared to chance, $t(17) = -2.48$, $p = .02$, two-tailed, Cohen's $d = -1.20$, $M = -.09$, $SE = .04$. A one-way ANOVA on the effect of switching sides between familiarization and test trials revealed no significant effects of switching on the average difference score, $F(1, 16) = .55$, $p = .47$

Discussion Infants in this experiment displayed a preference for the inconsistent split, similar to the preference in Experiment 1 (No Cue condition) and Experiment 2 (Social Cue condition). Interestingly, infants showed this preference despite a) being exposed to an equally salient pattern in the other frame during familiarization, and b) looking for a short amount of time to the target event compared to the other three conditions. These findings suggest that social cues elicit rapid learning in a noisy environment. Infants did not seem to process much of the distracter pattern, as they would have preferred the opposite event otherwise.

General Discussion

We have shown that 9-month-old infants use visual feature co-occurrences to form representations of object integrity, and that with multiple streams of visual information available in their environment, infants will use social cues to select the ones that they learn. First, these findings extend previous work showing that infants recognize visual feature co-occurrences (Fiser & Aslin, 2002) by demonstrating that infants consider co-occurring features as a larger perceptual unit that should remain fused. If this is the case, then infants may consider these larger perceptual units as integral to an object, as is the case with adults (see Scholl, 2001). Therefore, it is plausible that tracking co-occurrences in infants (as in adults) supports essential skills such as object recognition, categorization, and word learning. The fact that statistics are useful for infants in the visual domain echoes findings in the auditory domain and in studies of causal inference. For example, infants use speech segments that are statistically consistent as labels for objects (Graf Estes et al., 2007). Importantly, these findings support the idea that statistical learning is a powerful mechanism that is *useful* and that leads to inferences beyond detection of the statistical pattern itself.

Social attention cues shaped infants' learning about objects, the second finding in our experiments. This effect remained despite the distraction of the face, change in test spatial layout, and additional distracter patterns during familiarization. Again, this finding in the visual domain is similar to those in the auditory domain showing that infant-directed speech and visual face stimuli facilitate word segmentation (Sell & Kaschak, 2009; Thiessen, Hill, & Saffran, 2005). Importantly, this study grounds an emerging literature showing that social cues mediate infants' basic learning via three key aspects: 1) using an explicit measure of learning, 2) comparing learning effects with and without social cues, and 3) investigating such learning with younger, prelinguistic infants. Together, these aspects allow for stronger evidence that social cues mediate learning from the first year.

One could ask whether the social character of the face drove the learning effect or whether a non-social cue would have been equally effective. Our previous work showed that when cued by flashing squares, 8-month-old infants remember *where* they were cued to rather than *what* they were cued to (Wu & Kirkham, in press). Another effective non-social central cue could be an interactive stimulus: If a stimulus interacts with the infant and then turns in one clear direction, the infant will follow the object's 'gaze' (e.g., Johnson, Slaughter & Carey, 1998). A recent study, however, showed that 18-month-olds do not map labels onto objects 'gazed' on by an interactive non-social stimulus, only those gazed on by human faces (O'Connell, Poulin-Dubois, Demke, & Guay, 2009), and this interactive stimulus might be argued to itself have social features. In future studies, we intend to find a suitable (and effective) non-social cue for this experimental paradigm. For now, we claim only that social cues facilitate visual statistical learning. We do not claim, however, that social cues are the *only* attention cues that aid learning, nor that they produce better learning than any other attention cue.

In conclusion, our findings suggest that co-occurrence information and social cues inform and direct learning in infancy. In particular, though social cues may temporarily detract attention away from certain learning events in the world, they appear to stimulate infants to display the learning better in complex situations than when infants learn on their own without attention cues. Investigating how infants interact with different cues in the environment (see Goldstein et al., in press) and the developmental trajectory of the use of such cues (e.g., Hollich, Hirsh-Pasek, & Golinkoff, 2000) would clarify the extent to which they shape cognitive development.

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